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by

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16. ABSTRACT The paper reviews Japanese activities in SO2 and NOx control. From 1970 to 1985, energy use in Japan increased by 25%, and annual coal consumption rose from virtually nothing to 20 million tonnes, yet emissions of SO2 declined by 75% and NOx by 40%. While increases in hydroelectric and nuclear energy sources and use of lower sulfur fuel oil have contributed to the emissions reduction, the most prominent technological achievements have occurred in the successful implementation of SO2 and NOx controls. Since 1968, nearly 1600 flue gas desulfurization (FGD) systems and 250 selective catalytic reduction (SCR) units have been constructed. Recent and current activities include simplified FGD operations, SCR experience in coal-fired systems, and transfer of control technology to waste-to-energy plants.

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From 1970 to 1985, energy use in Japan increased by 25% and annual coal consumption rose from virtually nothing to 20 million tonnes, yet emissions of SO_2 declined by 75% and NO_x by 40%. While increases in hydro and nuclear energy sources and use of lower sulfur fuel oil have contributed to the emissions reduction, the most prominent technological achievements have occurred in the successful implementation of SO_2 and NO_x controls. Since 1968, nearly 1600 flue gas desulfurization (FGD) systems and 250 selective catalytic reduction (SCR) units have been constructed. Recent and current activities include simplified FGD operations, SCR experience in coal-fired systems, and transfer of control technology to waste-to-energy plants.

FLUE GAS DESULFURIZATION [1, 2, 3]

Initially the FGD market in Japan was dominated by sodium scrubbing plants which produced by-product sodium sulfite used by paper mills. This demand was quickly met, resulting in the installation of gypsum-producing FGD processes in the early 1970s. Except for one brief period in 1974-76, the demand for gypsum has exceeded the supply in Japan, hence the recent and current dominance of lime/limestone FGD systems in Japan continues.

Table 1 shows wet FGD plants by major constructors in Japan. Nearly all coal-fired boilers and most larger plants, whether oil or coal, use wet-limestone-gypsum processes. About 55% of total FGD capacity, or 130 plants totaling 24,000 MWe equivalent capacity, use wet limestone with forced oxidation. Another 72 plants use indirect and/or modified lime/limestone-gypsum (double alkali) processes. Many of the double alkali systems were constructed in the earlier

TABLE 1. WET FGD PLANTS BUILT BY MAJOR CONSTRUCTORS
(Operational by the end of 1987)

Plant Constructor	Number (Capacity, 1000 Nm^3/h)				
	Wet lime/ limestone	Indirect/modified lime/limestone	H_2SO_4, S $(NH_4)_2SO_4$	Na_2SO_3, Na_2SO_4, $MgSO_4$	Total
Mitsubishi Heavy Industries (MHI)	47(35,254)	—	—	3(292)	50(35,546)
Ishikawajima-Harima H.I. (IHI)	24(12,719)	—	—	26(3,240)	50(15,959)
Hitachi Ltd./Babcock Hitachi	22(14,167)	—	2(590)	19(843)	43(15,600)
Kawasaki Heavy Industries (KHI)	2(174)	12(8,376)	—	7(256)	21(8,806)
Mitsubishi Kakoki (MKK)	5(506)	—	13(6,606)	5(1,165)	23(8,277)
Chiyoda Chemical Eng. Construc.	5(2,436)	13(4,375)	—	—	18(6,811)
Fujikasui Engineering	7(4,144)	—	—	22(2,405)	29(6,549)
Oji Engineering	—	—	—	32(6,239)	32(6,239)
Kurabo Engineering	—	5(558)	1(18)	105(4,249)	111(4,825)
Mitsui Miike Engineering	6(3,653)	—	3(760)	—	9(4,413)
Tsukishima Kikai (TSK)	1(80)	4(430)	2(325)	31(3,533)	38(4,368)
Ebara Corporation	1(26)	11(1,520)	—	10(2,006)	22(3,552)
Nippon Kokan (NKK)	3(197)	1(150)	2(1,990)	—	6(2,337)
Kobe Steel	—	6(1,925)	—	—	6(1,925)
Kureha Chemical	—	1(40)	—	7(1,380)	8(1,420)
Dowa Engineering	—	16(1,408)	—	—	16(1,408)
Shoden Engineering	—	3(1,002)	—	2(370)	5(1,372)
Mitsui Metal Engineering	4(1,006)	—	2(130)	—	6(1,136)
Ube Industries	—	—	2(210)	1(600)	3(810)
Sumitomo Chemical Engineering	—	—	5(748)	—	5(748)
Niigata Iron Works	2(265)	—	—	2(220)	4(485)
JGC Corporation	1(330)	—	1(125)	—	2(455)
Total	130(74,957)	72(19,784)	33(11,502)	272(26,798)	507(133,041)

period of FGD development, 1972-76, when scaling problems were not uncommon with lime/limestone FGD. As the reliability and economic advantages of lime/limestone FGD have improved, the recent construction of double alkali systems has diminished.

Table 1 also shows 33 regenerable process FGD systems, of which 20 produce sulfuric acid, 5 produce ammonium sulfate, and the remainder generate elemental sulfur. The sulfur producing systems are located at oil refineries where existing sulfur recovery facilities economically favor FGD sulfur production.

Numerically the dominant FGD system in Japan is sodium scrubbing, since many smaller and older FGD units in Japan still use clear liquor systems which produce sodium sulfite for paper mills, sodium sulfate for the glass industry, or waste sodium sulfate liquor. In addition to the plants listed in Table 1, nearly 1000 additional sodium systems operate in Japan on smaller commercial and industrial fossil-fuel combustors with an average unit capacity of 3.3 MWe equivalent. Lately about 20 magnesium-based FGD units have been constructed where sodium scrubbing would have normally been chosen, due to the lower cost of magnesium hydroxide reagent compared to sodium hydroxide or sodium carbonate.

RECENT FGD TRENDS IN COAL-FIRED UTILITY BOILERS [1, 2, 3]

To illustrate the types of FGD systems currently considered for utility application in Japan a classification system has been prepared by author Ando, as shown as Table 2 and illustrated as Figure 1. In this scheme, FGD processes are divided into nine major types according to by-product produced, absorbent, additive, use of prescrubbers, and use of sulfuric acid for pH control. Type I is the most popular system in the United States, but has been limited to one installation in Japan due to a lack of space for sludge disposal. Type II systems use an extra scrubber to lower the pH by further SO_2 absorption and add sodium hydroxide or sulfate to promote SO_2 absorption and oxidation. Three plants currently use Type II FGD systems.

TABLE 2. CLASSIFICATION OF WET LIME/LIMESTONE PROCESSES

Type	By-Product	Absorbent	Additive	Prescrubber[a]	Sulfuric acid[b]
I	Sludge	$Ca(OH)_2$	None	No	No
II	Gypsum	$CaCO_3$	Sodium	No	No
III, VII	Gypsum	$CaCO_3$	Sodium	No	Yes
IV	Gypsum	$CaCO_3$	None	Yes	Yes
V	Gypsum	$CaCO_3$	None	Possible	No
VI	Gypsum	$Ca(OH)_2$	MgO[c]	Possible	No
VIII	Gypsum	$CaCO_3$	None	Yes	No
IX	Gypsum	$CaCO_3$	Probable	No	No

[a] In a separate liquor loop; some waste liquor and sludge likely with prescrubber.
[b] To promote oxidation.
[c] No need when lime contains over 1% MgO.

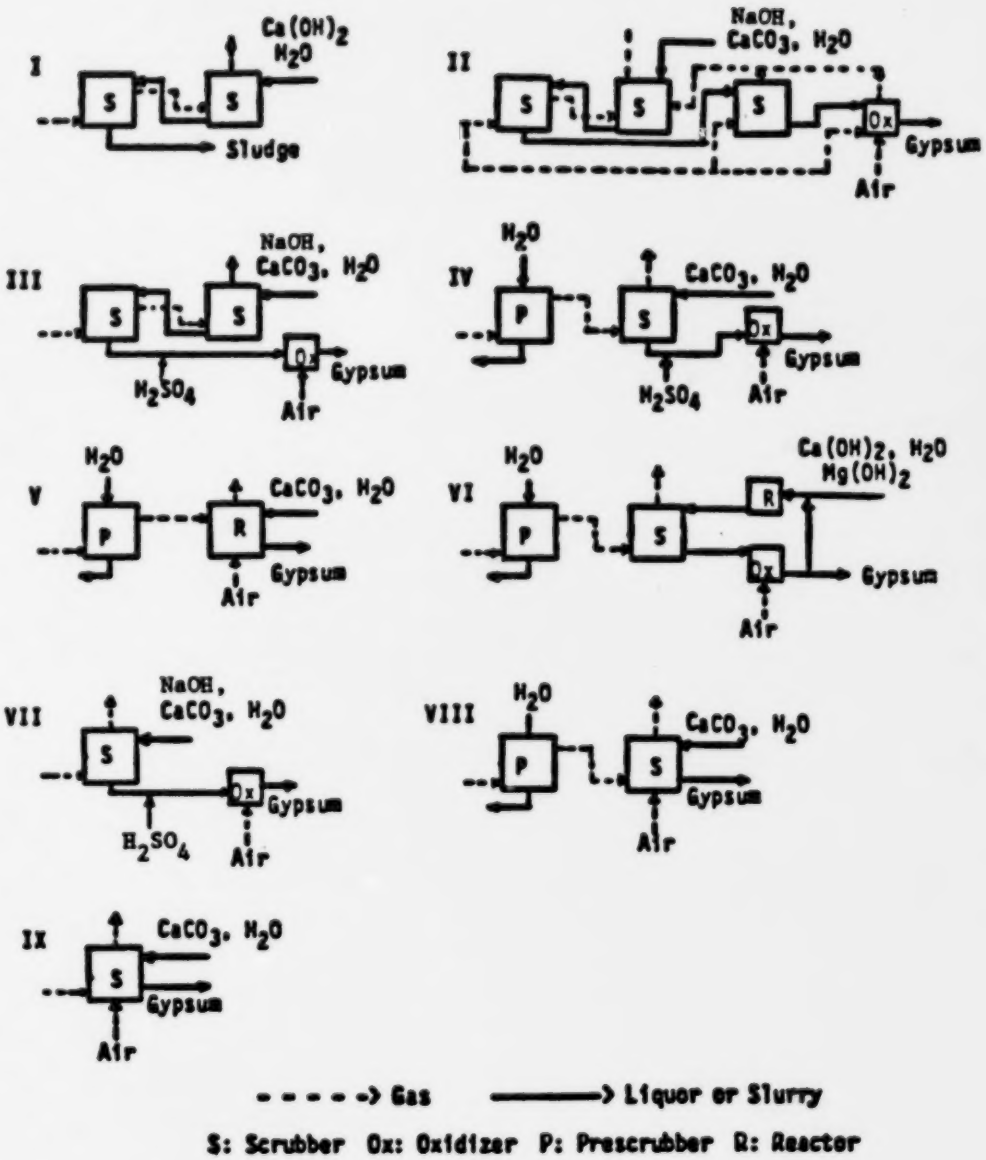

Figure 1. Wet lime/limestone process classifications.

In Type III FGD systems, the slurry pH is lowered by sulfuric acid addition and often uses a sodium promoter as do Type II systems. Four Type III plants are in operation.

Type IV, developed by Mitsubishi, is the most popular system, utilizing a prescrubber with the following functions: (1) removal of fluorides and chlorides which adversely affect FGD chemistry and materials, (2) dust removal (hence increased purity of by-product gypsum), and (3) cooling of gas and prevention of scaling. However, the prescrubber does add to system cost and produces waste liquor and sludge. Type V represents the jet bubbling reactor developed by Chiyoda, while Type VI by Kawasaki Heavy Industries uses a lime-magnesium system. Types V and VI do not use sulfuric acid. Type VII is a simplification of Type III, developed by Mitsui Miike Engineering. Types VIII and IX are new simplified concepts featuring lower power requirements and are more suited for lower sulfur fuels.

Table 3 lists FGD units constructed since 1977. All plants have electrostatic precipitators (ESPs) to remove 97-99.6% of particles and wet lime/limestone gypsum FGD units to remove 90-98% SO_2 and an additional 70-90% of particulate matter. Of the most recently installed units (1985-87), four of the seven units shown were Type IV FGD systems. A few Type IX plants are currently under construction.

NO_x CONTROL [1, 2, 3]

The vast majority of NO_x emitters in Japan meet current regulations by combustion modification techniques. However, essentially all new coal-fired utility boilers in Japan will be required to install post-combustion NO_x controls due to local agreements and recently tightened Federal (Central Government) NO_x emission standards. Combustion modifications such as flue gas recirculation (FGR), two-stage combustion (TSC), and low-NO_x burners are currently used singly and in combination to allow less strenuous operation of post-combustion NO_x controls; therefore, in the ensuing discussions the reader should keep in mind that flue gas NO_x levels are already reduced by 50-70% over uncontrolled levels.

The most advanced flue gas treatment process is selective catalytic reduction (SCR). In this technique NO_x is reduced to elemental nitrogen, N_2, and water vapor by ammonia (NH_3) injection in the presence of a catalyst. SCR usually removes 60-85% of NO_x using 0.6-0.9 moles NH_3 per mole NO_x and leaves 1-5 ppmv unreacted NH_3. The optimum flue gas temperature for SCR is 300-400°C; therefore, SCR is usually applied upstream of FGD at the boiler economizer outlet.

In the earlier stages of development, SCR had several problems:

- o catalyst poisoning by SO_x
- o plugging of catalyst by fly ash
- o ammonium bisulfate deposition on SCR catalyst (below 300°C)
- o ammonium bisulfite deposition in air preheaters (below 250°C)
- o oxidation of SO_2 to SO_3
- o errosion of catalyst by fly ash

TABLE 3. FGD AND SCR UNITS COMPLETED SINCE 1977 FOR COAL-FIRED UTILITY BOILERS

Owner	Station name	Boiler (MW)	FGD Constructor	FGD completion	FGD Type	SCR Constructor	SCR completion	SCR Type
EPDC	Takehara	250	BHK[a]	1977	III	BHK, KHI[b]	1980	L[c]
Chugoku Elec.	Shimonoseki	175	MHI[d]	1979	IV	MHI	1980	H[e]
Hokkaido Elec.	Tomato	350[f]	BHK	1980	IV	BHK	1980	L
EPDC	Matsushima	500x2[g]	BHK, IHI[h]	1981	IV	-	-	-
Chugoku Elec.	Shin-Ube	75x2	MHI	1982	IV	MHI	1982	H
Chugoku Elec.	Shin-Ube	156	MHI	1982	IV	MHI	1982	H
Kyushu Elec.	Omura	156	MHI	1982	IV	-	-	-
EPDC	Takehara	700	IHI	1983	III	BHK	1983	L
Joban Joint	Nakoso	600[i]	MHI	1983	IV	MHI	1983	H
Joban Joint	Nakoso	600[i]	MHI	1983	IV	IHI	1983	H
Kyushu Elec.	Minato	156	MME[j]	1983	VII	MHI	1983	H
Shikoku Elec.	Saijo	156	KHI	1983	VI	MHI	1983	H
Tohoku Elec.	Sendai	175x2	BHK	1983	IV	BHK	1983	H
Shikoku Elec.	Saijo	250	KHI	1984	VI	IHI	1984	H
Chugoku Elec.	Mizushima	125 & 156	BHK	1984	IV	BHK	1984	H
Sakata Joint	Sakata	350	MHI	1984	IV	MHI	1984	H
Toyama Joint	Toyama	200x2	Chiyoda	1984	V	BHK	1984	H
Tokyo Elec.	Yokosuka[k]	265	MHI	1984	IV	MHI	1984	H
Tokyo Elec.	Yokosuka[k]	265	BHK	1985	IV	MHI	1985	H
Hokkaido Elec.	Tomato	600	MHI	1985	IV	-	-	-
Chugoku Elec.	Shin-Onoda	500	IHI	1986	IV	IHI	1986	H
EPDC	Ishikawa	125	IHI	1986	III	-	-	-
Chugoku Elec.	Shin-Onoda	500	IHI	1987	IV	IHI	1987	H
EPDC	Ishikawa	125	IHI	1987	VII	-	-	-
Kyushu Elec.	Matsuura	700	MHI	1987	VIII	MHI	1987	H

[a]Babcock Hitachi K.K.
[b]Kawasaki Heavy Industries
[c]Low-dust system
[d]Mitsubishi Heavy Industries
[e]High-dust system
[f]Subjecting 50% of gas to FGD and 25% of gas to SCR
[g]Subjecting 75% of gas to FGD
[h]Ishikawajima-Harima Heavy Industries
[i]Burns both coal and oil
[j]Mitsui Miike Engineering (former Mitsui Miike Machinery)
[k]Burns a coal/oil mixture

The following countermeasures were developed and have generally proven successful:

- o use of base metal catalysts with TiO_2 instead of Al_2O_3 or Fe_2O_3 substrates
- o use of parallel-flow catalysts such as honeycomb, plate, and tube catalysts
- o use of an economizer bypass to ensure operation above 330°C
- o maintaining unreacted NH_3 below 3 ppmv
- o use of a low-oxidation catalyst
- o employing erosion mitigation measures consisting of reduced gas velocities, harder catalysts, and dummy spacers

Major SCR plant constructors and the number and capacity of the plants constructed by them are shown in Table 4. Nearly all of the plants for utility boilers have been constructed since 1979, while virtually all the industrial plants were constructed before 1978. Some of the older plants experienced the problems described previously; however, nearly all plants constructed since 1979 have operated without problems in an automatic control mode.

SCR FOR UTILITY BOILERS [1, 2, 3]

Table 5 shows SCR performance for 13 major utility boilers in Japan. Coal-fired systems typically are parallel-flow catalysts with a space velocity (SV) of 2000-4000 h^{-1} to remove 60-80% of NO_x; those with low-sulfur oil-firing typically use parallel-flow catalysts with SV higher than 5000 h^{-1} to remove 80% NO_x. The lower SV for coal results from the higher inlet NO_x and SO_2 concentrations which mandate less reactive, lower oxidation catalysts. SCR plants for gas-fired boilers use pellet catalysts having an SV of 20,000 h^{-1}.

Between 1983 and 1987, 32 new SCR plants were constructed on utility boilers, 15 new and 17 retrofit.

Performance for a utility boiler SCR unit includes the following considerations:

(1) During boiler load swings, the NO_x removal usually is inversely proportional to load, due to the smaller space velocity or longer reaction times at lower loads.

(2) Lower loads usually mean lower flue gas temperatures which may increase deposits of ammonium bisulfate on the catalyst. Economizer bypass may be used to maintain higher temperature in the catalyst bed. When bypass is used less heat is recovered by the economizer, but is compensated by increased heat recovery in the air preheater downstream.

(3) The concentration of unreacted NH_3 is held below 3 ppmv to minimize bisulfate problems.

(4) Low-dust systems (downstream of hot-side ESP) encounter less catalyst erosion by dust but may be penalized by higher ESP costs and more deposits in the air preheater. The system is suited for low-sulfur coals.

TABLE 4. NUMBER AND CAPACITY OF SCR PLANTS BY JAPANESE MAKERS
(Completed by end of 1986)

Maker	For utility (Capacity in MWe)			Industry (1000 Nm^3/h)		In foreign countries (MWe)	Total (MWe) equivalent[a]
	For coal	For oil	For gas	Boiler	Others		
Mitsubishi Heavy Industries	12 (3233)	26 (8641)	11 (3421)	20 (2080)	1 (227)	9 (1277)	79 (17341)
Babcock Hitachi K.K.	9 (1944)	18 (5059)	3 (2100)	5 (101)	6 (586)	4 (822)	45 (10154)
Ishikawajima-Harima H.I.	4 (816)	14 (5818)	1 (700)	3 (764)	0	9 (682)	31 (8271)
Hitachi Zosen	0	0	7 (1000)	3 (940)	7 (951)	0	17 (1630)
Sumitomo Chemical Eng.	0	0	0	3 (640)	13 (1035)	0	16 (558)
Mitsui Eng. & Shipbuilding	0	0	0	4 (566)	13 (1019)	0	17 (528)
Kawasaki Heavy Industries	1 (125)	0	1 (156)	4 (131)	2 (12)	3 (122)	11 (451)
Nippon Kokan	0	0	0	0	1 (1320)	0	1 (440)
Techno Universe[b]	0	0	0	4 (332)	4 (615)	5 (117)	13 (433)
Ube Industries	0	0	0	3 (548)	1 (75)	0	4 (208)
Mitsubishi Kokoki	0	0	0	2 (114)	7 (222)	0	9 (112)
JGC Corp.	0	0	0	2 (120)	1 (152)	0	3 (91)
Kobe Steel	0	0	0	0	1 (100)	0	1 (33)
Total	26 (6118)	58 (19518)	23 (7377)	53 (6336)	57 (6314)	30 (3020)	247 (40250)

[a]Calculated at 1 MWe = 3000 Nm^3/h
[b]Jointly with Mitsui Toatsu Chemical

TABLE 5. PERFORMANCE OF MAJOR SCR UNITS ON UTILITY BOILERS

Fuel	Plant owner	Plant site	Boiler No.	Boiler MW	SCR mfr	Catalyst type	Pitch (mm)	SV (h^{-1})	NO_x conc (ppmv) In	NO_x conc (ppmv) Out	$DeNO_x$ (%)	Unreacted NH_3 (ppm)	Start-up year
COAL	EPDC	Takehara	1	250x1/2	BHK[a]	Plate	10	2300	350	67	81	4	1981
	EPDC	Takehara	2	250x1/2	KHI[b]	Tube	-	2000	350	67	81	4	1981
	EPDC	Takehara	3	700	BHK	Plate	10	2370	250	48	81	2	1983
	Chugoku	Shimonoseki	1	175	MHI[c]	Honeycomb	10	3000	420	180	57	1	1980
	Chugoku	Shin-Ube	3	156	MHI	Honeycomb	7	4000	400	140	65	2	1981
	Chugoku	Mizushima	2	156	BHK	Plate	6	2200	350	120	65	2	1984
	Shikoku	Saijo	1	156	MHI	Honeycomb	7	4000	380	130	65	1	1983
	Shikoku	Saijo	2	250	IHI[d]	Honeycomb	7.5	-	330	90	70	1	1983
OIL (Low S)	Chugoku	Kudamatsu	2	375	IHI	Honeycomb	-	5500	150	28	81	5	1979
	Chugoku	Kudamatsu	3	700	IHI	Honeycomb	-	5500	110	21	81	6	1979
	Chubu	Chita	4	700	MHI	Honeycomb	8	5430	100	18	82	2	1979
GAS	Chubu	Chita	5,6	700	BHK	Pellet	5	20000	40	8	80	4	1975
	Chubu	Chita II	1	700	BHK	Pellet	5	20000	50	10	80	4	1983

[a] Babcock Hitachi K.K.
[b] Kawasaki Heavy Industries
[c] Mitsubishi Heavy Industries
[d] Ishikawajima-Harima Heavy Industries

(5) High-dust systems (upstream of ESP) encounter more dust errosion but have less reactor and air preheater deposits and lower ESP costs. This system is better suited for medium- to high-sulfur coal, and is more common in Japan than the low-dust system.

OTHER PROCESSES FOR SO_x and NO_x ABATEMENT [2, 3]

Between 1972 and 1978, approximately 30 pilot- or small-scale wet process NO_x or simultaneous SO_x/NO_x removal units were constructed. Due to high costs and or relatively low NO_x removal efficiencies, recent development has focused on dry processes as shown in Table 6.

TABLE 6. DRY PROCESSES FOR NO_x AND SO_x/NO_x ABATEMENT (Other than SCR)

NO_x control only	
Selective noncatalytic reduction (SNR or Thermal $DeNO_x$)	Exxon, Mitsubishi Chemical, Mitsubishi Heavy Industries, Mitsubishi Kakoki
In-furnace NO_x reduction (IFR or Reburning)	Mitsubishi Heavy Industries, Hitachi Zosen
Molecular sieve adsorption	Union Carbide-Nissan Chemical
Simultaneous SO_x/NO_x removal	
Activated carbon adsorption	Unitika, Electric Power Federation Electric Power Development Co., Sumitomo Heavy Industries, Mitsui Mining-Bergbau Forschung
Electron beam irradiation	Ebara Corp.
Copper oxide	Shell
Fluidized bed combustion	Electric Power Development Co., Kawasaki Heavy Industries, Mitsubishi Heavy Industries

For NO_x removal only, selective noncatalytic reduction (SNR, or Thermal $DeNO_x$) has been applied to smaller furnaces and boilers firing natural gas and low-sulfur oil to remove 30-40% of NO_x at a 1:1 NH_3/NO_x molar ratio. Recent applications of SNR to refuse incinerators have been made to remove 50-60% NO_x at 1.5-2 moles NH_3 to 1 mole NO_x. In-furnace reburning (IFR) has been applied commercially in Japan to coal- and oil-fired boilers at up to 50% additional NO_x removal over levels achieved by combustion modification (staged

combustion) techniques alone. Molecular sieve adsorption of NO_x has been operated at a nitric acid plant since 1976 for 90% NO_x removal. Adverse effects of SO_2 have precluded any application to boilers.

For simultaneous dry SO_x/NO_x removal, two demonstration plants -- EPDC at 95 MWe and Mitsui Mining at 10 MWe -- have been operated using activated coke as the adsorbent to produce elemental sulfur by-product. The EPDC plant removes 30% NO_x and 95+% SO_2, while the Mitsui plant removes 60-80% NO_x and 98% SO_2. Mitsui Mining recently completed a commercial plant, 75 MWe, for Idemitsu Kosan at the Aichi Refinery.

Other combined processes for SO_x/NO_x removal include the Copper Oxide process which operated for several years on an oil-fired boiler but was aborted due to high cost, and the Electron Beam process which has been operated on a pilot plant basis.

Finally, fluidized bed combustion (FBC) has been applied to about 20 small boilers (20,000-320,000 lbs/hr steam capacity) since 1980. However, the prognosis for FBC is not good in the utility sector due to (1) stringent SO_2 and NO_x regulation, (2) generation of a lime-rich waste disposal problem, and (3) limitations of FBC for intermittent operations with load swings and frequent start-up/shut-down cycles.

WASTE-TO-ENERGY PLANTS [4]

Municipal solid waste is generated in Japan at about 120,000 tonnes per day, with 70% burned in mass-burn or fluidized bed waste-to-energy plants. Energy recovered is used to meet all or part of the electrical demand and heating/cooling requirements of the plant and nearby municipal facilities. In general, no energy is transferred outside the local service area.

ACID GAS/SO_2 CONTROL [4]

SO_2 control is not critical as the concentration from waste combustion is typically 60 ppmv (12% O_2 basis). However, hydrochloric acid (HCl) vapor is typically 700 ppmv and requires control by addition of alkali to the furnace or flue gas, hence SO_2 control is achieved concurrently. Limestone injection into the furnace zone is reported to reduce HCl by 25-40% at a $CaCO_3$/HCl molar ratio of 1:1 and by 80-85% at a ratio of 4:1. Since many local agreements require HCl reduction to less than 50 ppmv, several combinations of dry injection, humidification, and wet scrubbers are used in Japan. Figures 2 and 3 show two types of scrubbing systems currently in use.

Wet scrubber systems (Fig. 2) generally use sodium hydroxide for HCl/SO_2 control and can add an oxidizing agent such as sodium chlorite ($NaClO_2$) to remove NO_2 as well. Where stringent heavy metals control and moderate (30-50%) NO_x removal is warranted, wet systems have economic advantages over dry systems; however, the complexity of operation is significantly increased. Semi-dry or dry injection with humidification systems, such as in Figure 3, use hydrated lime, $Ca(OH)_2$, and is the dominant control system in Japan for waste firing. As indicated in Figure 3, virtually all HCl and 85% SO_2 removal can be typically achieved.

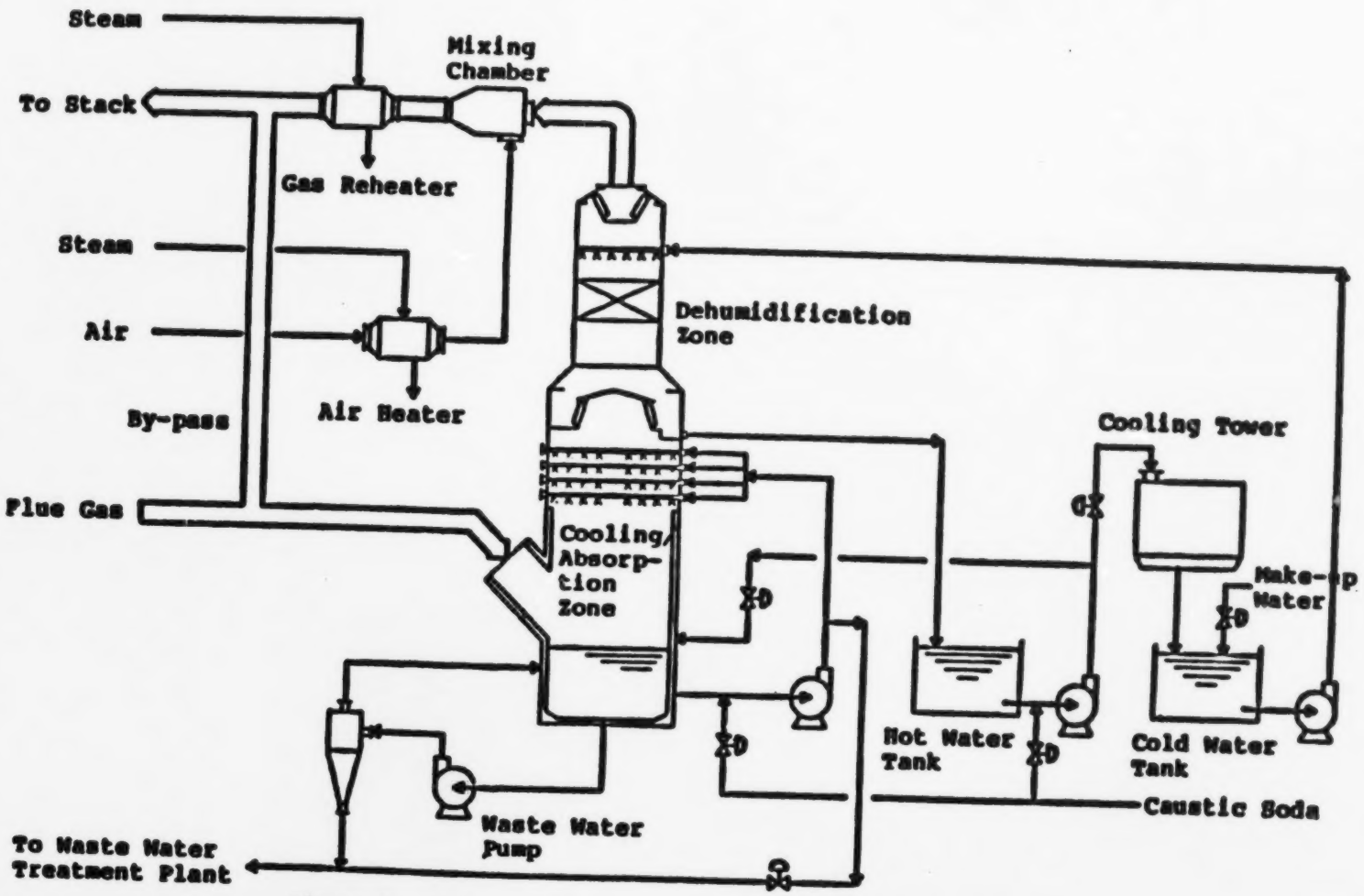

Figure 2. Wet type flue gas scrubbing system flow diagram.
(Courtesy of Hitachi Zosen Corp.)

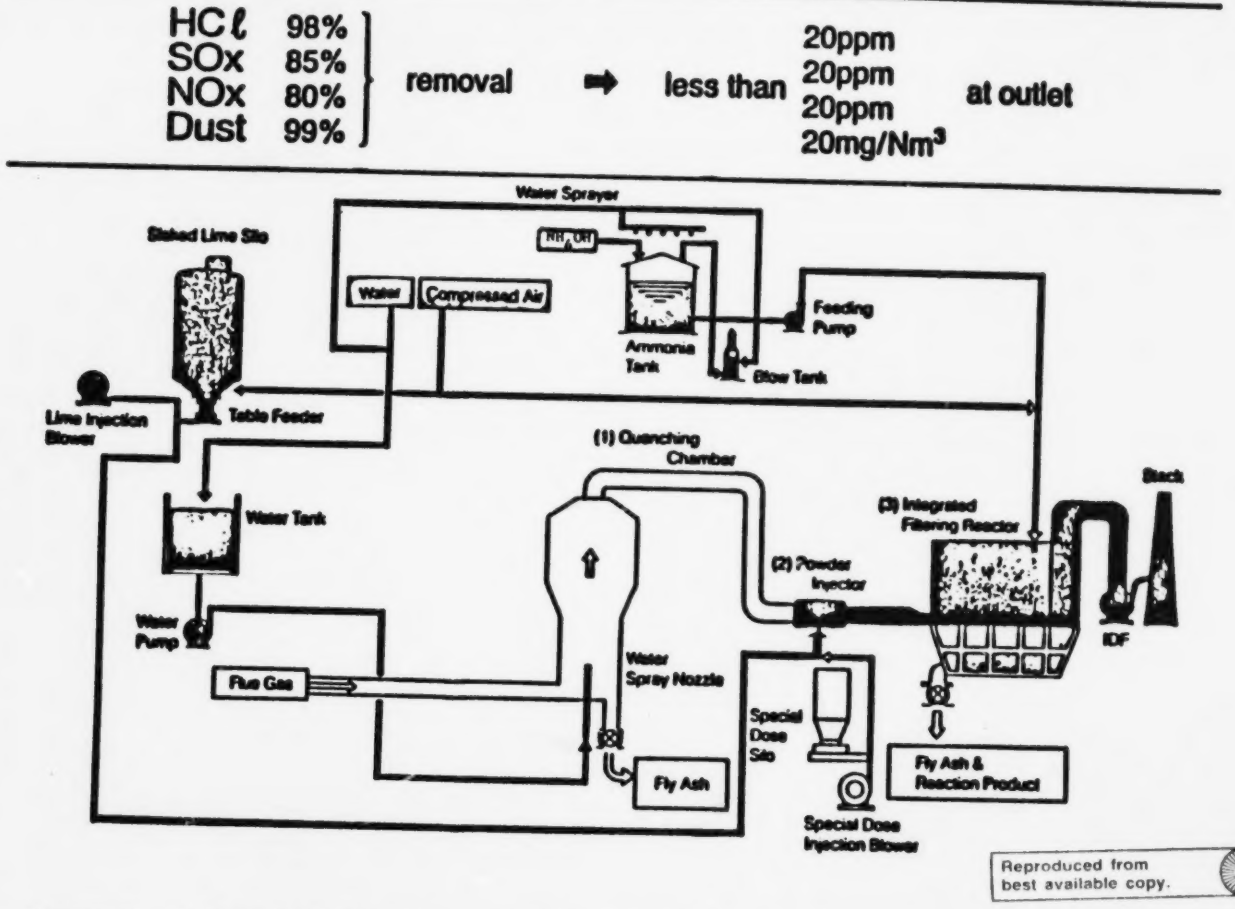

Figure 3. Integrated flue gas treatment system with pollutant removal capabilities. (Courtesy of Mitsubishi Heavy Industries, Ltd)

NO_x CONTROL [4]

Dry NO_x control is achieved in waste-to-energy plants by either in-furnace, selective noncatalytic reduction (SNR) or post-combustion selective catalytic reduction (SCR). Table 7 shows a sampling of plants using SNR, where typically 30-60% NO_x removal is achieved at 2-3.5 molar ratios of NH_3 to NO_x. The plants use aqueous ammonia (to prevent thermal damage to injection nozzles) sprayed into the furnace at about 900°C.

TABLE 7. SNR PLANTS BY MHI FOR REFUSE INCINERATORS

Location (city)	Unit Capacity Nm^3/h	Number of units	NO_x (ppm, 12% O_2) Inlet	NO_x (ppm, 12% O_2) Outlet	Completion year
Toyohaski	24,500	2	150	60	1980
Kamakura	32,000	2	175	100	1982
Kawasaki	48,540	3	200	(800 g/ton)[a]	1982
Kobe	45,000	3	180	130	1984
Yokohama	136,680	3	150	100	1984
Nagoya	47,000	3	150	80	1985
Kawasaki	70,310	2	150	(800 g/ton)[a]	1986
Kawasaki	47,000	3	200	(800 g/ton)[a]	1986
Hiroshima	38,740	2	150	100	Under construction

[a] About 100 ppm

Table 8 shows SCR units applied to 15 sewage sludge incinerators by Mitsui Engineering. Generally 90% NO_x removal can be achieved at 1:1 molar NH_3/NO_x ratio. Upstream dust removal and HCl reduction to below 20 ppmv is accomplished by sodium scrubbing. The gas is heated to 350-400°C for SCR. Catalyst life of 6 years is reported.

More recently, Mitsubishi (MHI) has constructed two SCR plants using a lower temperature (~200°C), HCl resistant catalyst. Advantages include significant savings in reheat costs and the ability to place the flue gas scrubber upstream (as in Figure 4) or downstream (wet scrubber) with little effect upon NO_x control costs or FGD operation. NO_x removal of 70% or greater has been achieved.

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TABLE 8. SCR PLANTS FOR INCINERATORS CONSTRUCTED BY MITSUI ENGINEERING

Plant name	City	Gas flow (Nm^3/h)	Inlet (ppm) NO_x	Inlet (ppm) SO_x	Temp. (°C)	$\frac{NH_3}{NO_x}$	NO_x removal (%)	Completion
Sunamachi	Tokyo	108,000	100	5	350	1.0	90	1979[a]
Nanbu No. 1	Tokyo	36,000	100	5	350	1.0	90	1983
Nanbu No. 2	Tokyo	36,000	100	5	350	1.0	90	1983
Kasia	Tokyo	9,700	100	5	350	1.0	90	1983
Hirano	Osaka	24,000	130	20	400	1.0	90	1983
Hoshutsu	Osaka	47,000	130	20	400	1.0	90	1983
Shingashi	Tokyo	22,100	100	5	400	1.0	90	1983
Shingashi	Tokyo	33,100	100	5	400	1.0	90	1983
Senda	Hiroshima	2,515 x 2	130	20	400	1.0	90	1984
Sunamachi	Tokyo	108,000	100	10	350	1.0	90	1985
Kosuge	Tokyo	9,550	400[b]	30	400	1.0>	90	1985
Tsumori	Osaka	40,000	150	50	400	1.0>	80	1985
Konan	Biwako	2,700	135	25	400	1.0>	90	1985
Hojin	Nagoya	27,000	130	20	350	1.0>	80	1986

[a]Catalyst was replaced in 1986, after 6 years operation.
[b]NO_x is high (odor is less) because of the use of fluidized bed incinerator, while other incinerators are multi-stage type.